

## **A comparative study on mesozooplankton abundance and diversity between a protected and an unprotected coastal area of Andaman Islands**

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### **Abstract**

The study was carried out to understand the variability in phytoplankton production (Chlorophyll *a*) and mesozooplankton diversity from two different shallow coastal regions of south Andaman viz. Port Blair Bay (PBB; the only real urban area among the islands) and Mahatma Gandhi Marine National Park; a Marine Protected Area (MPA) at Wandoor. Seasonal sampling was carried out during the Northeast monsoon (NEM - November 2005), Intermonsoon (IM - April 2006) and Southwest monsoon (SWM - August 2006). Significant ( $P < 0.05$ ) seasonal variation was observed in the environmental variables at both the regions. Higher average chlorophyll *a* (Chl. *a*) and mesozooplankton standing stock were observed at PBB compared to MPA, but, the seasonal variation observed was marginal at both the study areas. Chl. *a* showed a steep increasing gradient from outer to the inner regions of the PBB. The number of zooplankton taxa recorded at both areas was quite similar, but marked differences were noticed in their relative contribution to the total abundance. Enentough the Copepoda dominated at both areas, the non-copepod taxa differed significantly between the study regions. Dominance of carnivores such as siphonophores and chaetognaths were noticed at PBB, while filter feeders such as appendicularians and decapod larvae were more abundant at MPA. Among the calanoid copepods, thirteen and eleven families were recorded at PBB and MPA, respectively. Twelve species of chaetognaths occurred at both the regions. Larval decapods were predominant at MPA and they belonged to twenty families while at PBB thirteen families and several brachyuran larvae were recorded. In the light of the recent reports on various changes occurring in the coastal waters of the Andaman Islands, it is suspected that the difference in Chl. *a* as well as the mesozooplankton standing stock and community structure observed between the two study areas may be related to the varying anthropogenic influences.

**Keywords:** Mesozooplankton, Andaman Islands, Marine Protected Area, Port Blair Bay.

## 1. Introduction

The mesozooplankton (0.2–20 mm) community is an integral part of the pelagic food web, since it is the interconnecting link between primary producers and higher trophic levels. They are the major consumers of phytoplankton, and play a significant role in the oceanic biogeochemical cycle of carbon and other elements (Buitenhuis et al. 2006). Although the distribution and diversity of mesozooplankton from the coastal waters of the Arabian Sea (Madhupratap et al. 1992; Madhupratap et al. 1996; Smith et al. 1998) and the Bay of Bengal (Nair et al. 1977; Achuthankutty et al. 1980; Nair et al. 1981; Rakesh et al. 2006) have been fairly well studied, only scanty information is available from the coastal waters of the Andaman Islands (IOBC, 1968; Marichamy, 1983), and thus this region still remains as one of the least explored areas of northern Indian Ocean. The Andaman and Nicobar Islands are bestowed with the richest coral diversity among all Indian reefs and one fifth of the country's total mangroves occur in these islands. Due to its remoteness from the mainland and because of the low urbanization and industrial activities, the pollution rate is also low. However, recent reports indicate the occurrence of phytoplankton blooms, abundance of indicator bacteria, sand mining, coral bleaching etc. from different coastal regions, particularly from the Port Blair among the Andaman group of islands (Dorairaj et al. 1997; Ravindran et al. 1999; Eashwar et al. 2001; Nallathambi et al. 2002; Vagholikar and Moghe, 2003). Most of these changes are generally accepted to be related to anthropogenic interferences. It is under these circumstances that the present study has been made an attempt to compare the seasonal (Northeast monsoon, Intermonsoon and Southwest monsoon) and spatial variations of mesozooplankton with respect to certain physical (temperature, Salinity and dissolved oxygen) and biological (Chlorophyll *a*) parameters, between two different shallow coastal regions of the south Andaman Islands. The study areas include Port Blair Bay (PBB), the only real urban area among these islands, and the Mahatma Gandhi Marine National Park (MGMNP) at Wandoor which is a Marine Protected Area (MPA). In addition to the taxa/group composition, the species/family diversity of copepods (the most dominant group), chaetognaths (a typical carnivore) and decapod larvae (a typical meroplankton component) have also been made.

## **2. Materials and Methods**

### **2.1. Study area**

Samples were collected from two different regions located on the east and west side of the south Andaman Island: (1) The Port Blair Bay (PBB) which is situated close to Port Blair, the only real urban area among these islands, and (2) a Marine Protected Area (MPA) known as the Mahatma Gandhi Marine National Park at Wandoor (Fig.1). The PBB extends as a narrow stretch in a northeast to southwest direction and opens in to the Andaman Sea. The six locations selected for sampling at PBB includes, near Light house (station 1), Rose Island (station 2), Aberdeen jetty (station 3), North Bay (station 4), Haddo jetty (station 5) and Viper Island (station 6). The MPA which is situated on the western side of the south Andaman is a very popular tourist spot, mainly because of its rich coral reef resources and scenic beauty. This area is a main nesting ground for sea turtles and is also well known for its rare marine resources, mangroves, corals, giant clams, reef fishes and estuarine crocodiles. Sampling was done from five locations at MPA viz. near Alexandra Island (station 1), Malay island (station 2), Jolly Buoy Island (station 3), Inter-Island (station 4) and Red Skin Island (station 5).

### **2.2. Sampling procedure and data analysis**

A boat was used for sample collection. Sampling was carried out during three seasons viz. Northeast monsoon (NEM-November, 2005), Intermonsoon (IM-April, 2006) and Southwest monsoon (SWM-August, 2006). Water samples for the analysis of Sea Surface Temperature (SST) Sea Surface Salinity (SSS), Dissolved oxygen (DO) and Chlorophyll *a* (Chl. *a*) were collected using a Niskin water sampler (Hydro-Bios 5 L). SST and SSS were measured using Bucket thermometer and Autosal, respectively. DO was estimated according to Winkler's titration method (Grasshoff et al. 1983). For the estimation of Chl. *a*, one litre of surface water was filtered through GF/F filters (pore size  $0.7\mu$ ), extracted overnight with 90% acetone and measured using spectrophotometer (Model-UV 1650PC, Shimadzu) before and after acidification (Strickland and Parsons, 1972). Mesozooplankton samples were collected by making 10 min horizontal hauls just below the surface (speed of the boat - 2 nautical miles per hour) at each location, with a WP-2 equivalent net (mesh size 0.2 mm, mouth diameter of 0.6 m), attached with a digital flow meter (General Oceanics, Model-2030). After removing detrital and

large gelatinous materials, biomass was estimated by displacement volume method. Samples were preserved in 5% buffered formaldehyde-sea water solution. Later in the laboratory, different taxa were sorted out using standard references (UNESCO, 1968; ICES, 2000). Copepods, chaetognaths and decapod larvae were identified to the lowest possible taxonomic level, under a dissecting microscope following standard references (Sewell, 1929; Tanaka, 1956; Kasturirangan, 1963; Alvarino, 1967). Due to difference in the number of sampling stations in the two areas, a two way nested ANOVA (Rhoif and Sokal, 1981; Jayalakshmy, 1998) was used for comparing environmental parameters with Chl. *a*, mesozooplankton biomass, total density and different species/families. Discriminant Analysis is a very useful tool for detecting the variables that discriminates between different (naturally occurring) groups, and for classifying cases into different groups with a better than chance accuracy (Snedecor, 1967; Jayalakshmy, 1998). Therefore, in this study discriminant analysis was also carried out using SST, SSS, DO, copepod density, chaetognath density and decapod larval density as the discriminating variables for PBB and MPA.

### **3. Results**

#### **3.1. Environmental variables (SST, SSS and DO)**

Depth of stations varied from 4 to 18 m at PBB and from 8 to 32 m at MPA. SST, SSS and DO showed significant seasonal difference ( $P < 0.05$ , Table 1) at both the regions. The spatial variations of environmental parameters at both the regions are illustrated in Figure 2 (a-c). Both SST (PBB - av. 29.9°C, MPA - av. 29.6°C) and SSS (PBB - av. 32.53, MPA - av. 32.45) recorded the highest values during IM season at both the regions and the least during SWM (SST: PBB - av. 27.2°C, MPA - av. 27°C; SSS: PBB - av. 31.21, MPA - av. 31.26). On the other hand, high average DO concentration was recorded during the monsoon seasons ([PBB: SWM (av. 4.78 ml l<sup>-1</sup>), NEM (av. 4.54 ml l<sup>-1</sup>); [MPA: SWM (av. 4.98 ml l<sup>-1</sup>), NEM (av. 4.65 ml l<sup>-1</sup>)].

#### **3.2. Chlorophyll *a* distribution**

Approximately a two fold increase in Chl. *a* was observed at the PBB (av. 1.72 mg m<sup>-3</sup>) as compared to MPA (av. 0.91 mg m<sup>-3</sup>). No marked seasonal difference was observed at PBB

(av. NEM: 1.34 mg m<sup>-3</sup>; IM: 1.86 mg m<sup>-3</sup> and SWM: 1.97 mg m<sup>-3</sup>), and at MPA (IM: 1.29 mg m<sup>-3</sup>; NEM: 0.80 mg m<sup>-3</sup>; SWM: 0.64 mg m<sup>-3</sup>). However high spatial variation was evident from outer to the inner region of the PBB during all the seasons and there is no such trend was observed at MPA (Fig.3). Among the stations in the bay, the innermost station near the Viper Island sustained the highest Chl. *a* during all the seasons.

### **3.3. Mesozooplankton biomass and abundance**

Average mesozooplankton standing stock as well as numerical abundance showed significant difference (Biomass, P<0.001, Density, P<0.001, Table 1) between the two study regions. PBB showed a six fold increase in biomass compared to MPA (Fig. 4). Similarly, the numerical abundance was around seven fold higher in the PBB than MPA (Fig. 5). As in the case of Chl. *a*, the seasonal variation of mesozooplankton biomass and numerical abundance was negligible within each study region (Table 1).

#### **3.3.1. Mesozooplankton community structure**

Twenty one taxa of mesozooplankton including both holo- and meroplankton were recorded from the study areas regardless of the seasons. The relative abundance of the dominant groups at different seasons are given in Table 2. Copepoda formed the most dominant taxon throughout the study period in both the regions (PBB; 82.9%, MPA; 85.9%). However, other groups showed marked differences in relative contribution between the two regions. At PBB abundance of siphonophores was noticed during all the three seasons and formed the second abundant group (8.5%) followed by chaetognaths (2.8%). At MPA, however, the relative contribution of appendicularians (4.6%) and decapod larvae (4.0%) was more compared to that of siphonophores (0.7%) and chaetognaths (1.3%). Cyprid larvae, gastropod larvae and foraminifera occurred only at PBB during SWM. Among the appendicularians, 96% was *Oikopleura* sp. and the rest was *Fritilaria* sp. Cladocera was present only at MPA, represented by *Evadne tergestina*. The other taxa in decreasing order of abundance were ostracods, ctenophores, polychaetes, medusae, doliolids, pteropods, euphausiids, amphipods, *Lucifer* sp, fish eggs and salps.

### 3.3.2. Copepod density distribution and diversity

Abundance of copepods was relatively high at PBB during all the three seasons (NEM: 1940 ind. m<sup>-3</sup>, IM: 1511 ind. m<sup>-3</sup> and SWM: 1222 ind. m<sup>-3</sup>) compared to MPA (NEM: 223 ind. m<sup>-3</sup>; IM: 265 ind. m<sup>-3</sup>; and SWM: 198 ind. m<sup>-3</sup>). Species belonging to four orders, viz. Calanioda, Cyclopoida, Poecilostomatoida and Harpacticoida were represented at both the areas. The Calanoida were dominant at both the regions (PBB: NEM-90.82%, IM-90.03% and SWM-93.71%; MPA: NEM-66.38%, IM-96.28% and SWM-87.45%) followed by Poecilostomatoida (PBB: NEM-9.04%, IM-9.20%, SWM-6.16%; MPA: NEM-28.00%, IM-3.15%, SWM-10.00%). Cyclopoids were relatively higher at both the regions (PBB: NEM-0.11%, IM-0.54%, SWM-0.08%; MPA: NEM-1.25%, IM-0.51%, SWM-2.44%) compared to harpacticoids (PBB: NEM-0.03%, IM-0.23%, SWM-0.05%; MPA: NEM-4.37%, IM-0.06%, SWM-0.11%). Thirteen and eleven copepod families were recorded at PBB and MPA, respectively. The relative contribution of different families in both regions is illustrated in Table 3a. Paracalanidae was the dominant family at both the regions throughout the study period (PBB: 62%; MPA: 44%). Eucalanidae, Calanidae, Corycaeidae, Clausocalanidae, Acartiidae and Oncaeidae, were the other dominant families occurred at both the areas and a striking increase (PBB: 38%; MPA: 25%) of eucalanids was noticed during SWM compared to other seasons. Oithonidae was the main cyclopoid observed and did not show any seasonal variation. Regardless of the seasons, a total of 26 and 31 species of copepods were encountered at PBB and MPA, respectively. *Bestiolina similis*, *Paracalanus* sp., *Acrocalanus* sp. *Oncaea venusta* and *Corycaeus* sp. were observed throughout the year and a high abundance of *Bestiolina similis* was noticed at PBB during NEM. The abundance of *Undinula vulgaris* was observed, particularly at Red skin station of MPA during NEM. Dominance of *Acartia erythraea*, *A. spinicauda*, *Labidocera pavo* and *L. minuta*, was observed only during IM season and the presence of species like *Lucicutia flavicornis*, *Pontella* sp., *Pleuromamma gracilis* were also noticed during this season. The abundance of harpacticoid copepod *Macrosetella gracilis* was observed more at MPA than at PBB. Statistical analysis showed both at PBB and MPA, the copepod families differed significantly in numerical abundance (PBB: P<0.05, MPA: P<0.01, Table 1) whereas the seasonal influence was marginal. Among the stations at PBB, Shannon Weiner diversity index was high at North Bay (1.49), Ross Island (2.50) and Haddo (2.26) during SWM, IM and NEM respectively (Table 4). At MPA it was high at Alexandra (2.61) during SWM, at Malai (1.68) during IM, at Alexandra (2.69) and

Red skin (2.32) during NEM. Seasonal diversity gradation was greater at MPA during NEM than SWM and IM while at PBB it was high during IM than NEM and SWM. Dominance gradation was SWM > NEM > IM at MPA and IM > NEM > SWM at PBB.

### 3.3.3. Chaetognath density distribution and diversity

The highest average population density of chaetognaths was observed at PBB during IM (67 ind. m<sup>-3</sup>) followed by NEM (30 ind. m<sup>-3</sup>) and SWM (21 ind. m<sup>-3</sup>), whereas it was very low at MPA during all seasons (NEM & IM: 2 ind. m<sup>-3</sup> and SWM: -1 ind. m<sup>-3</sup>). A total of thirteen species were identified from the study regions, belonging to the genera *Khronitta*, *Pterosagitta* and *Sagitta*. The percentage contribution of different species during the three seasons is illustrated in Table 3b. *Sagitta enflata* and *S. neglecta* formed the predominant species and contributed > 60% of the total density in both the regions. *Sagitta meenakshiae* was observed during all seasons at PBB and was abundant during IM (31.1%) but it was poorly represented at MPA. *S. pacifica* was observed only at PBB and *S. pulchra* only at MP. At PBB the species distribution showed significant spatial variability ( $P < 0.05$ ) with an added variance component of seasonal influence ( $P < 0.05$ , Table 1) and the highest species diversity was observed at Aberdeen during SWM (1.61) and NEM (1.50) and at North Bay (2.10) during IM (Table 4). At MPA both spatial and seasonal variation was found as insignificant and species diversity index was highest at Inter Island during SWM (1.81) and NEM (1.5) and at Jolly Bouy during IM (1.60). Seasonal diversity gradation at MPA was greater during SWM than IM and NEM, while at PBB it was higher during the IM than SWM and NEM. Dominance gradation for species was IM > SWM > NEM at MPA and IM > SWM > NEM at PBB.

### 3.3.4. Density distribution and diversity of Decapod larvae

The highest average population density of decapod larvae was observed at MPA (NEM: 8 ind. m<sup>-3</sup>; IM: 3 ind. m<sup>-3</sup>; and SWM: 5 ind. m<sup>-3</sup>) than at PBB (NEM: 1.8 ind. m<sup>-3</sup>; IM: 1.3 ind. m<sup>-3</sup>; and SWM: 1.7 ind. m<sup>-3</sup>). Decapod larval stages belonging to twenty families and several brachyuran larvae were identified from MPA, whereas only twelve families and brachyuran larvae were identified from the PBB. Percentage contributions of different families at both regions are illustrated in Table 3c. Seasonal variation was reflected in the decapod larval distribution and the maximum number of families was observed during SWM. The relative

contribution of most of the families showed an increase during SWM, particularly at MPA. Brachyuran larvae were abundant during all the seasons, particularly during NEM at both regions. Alpheidae, Palaemonidae and brachyuran larvae were dominant at both the regions during all the seasons. An increase in Palaemonids was noticed during IM at both the regions. At PBB, the decapod larval distribution was more under regional influence ( $P < 0.05$ , Table 1) than seasonal variation, whereas at MPA it showed significant seasonal and spatial variations ( $P < 0.05$ , Table 1). Shannon Weiner diversity index was the high at Malai Island (2.76) during SWM, at Redskin (2.87) during IM, and at Alexandra (2.61) during NEM at MPA whereas at PBB it was high at Inter Island (1.81), North Bay (2.12) and Viper Island (2.56) during SWM, IM and NEM, respectively (Table 4). The seasonal diversity gradation at MPA was high during SWM followed by NEM and IM whereas at PBB it was high during NEM than SWM and IM. Dominance gradation was  $NEM > SWM > IM$  at MPA and  $SWM > IM > NEM$  for PBB.

### **3.4. Canonical discriminant function/analysis (CDA/CDF)**

The analysis obtained significant Eigen value (79.28) with canonical correlation of 0.99. This discriminant function was found to be statistically significant (Wilks' Lambda = 0.01246, with  $\chi^2 = 65.78$  for 28 degrees of freedom,  $P < 0.00007$ ), indicating that the discriminant function was significant to discriminate between the two areas (Table 5, Fig. 6). On applying the cross validation 64.5% of the cross validated cases were correctly classified for the two regions. This analysis was also done to elucidate the predictor variables to distinguish between the seasons in the two areas. Five canonical discriminant functions were highly significant separating the three seasons in the two study areas with Wilks Lamda ranging between  $0.8 \times 10^{-7}$  and 0.19 and  $\chi^2$  ranging between 24.22 (21 dof) and 236.78 (125 dof). On cross validation it was observed that 17%, 17% and 67% of PBB NEM, PBB SWM and MPA SWM were correctly classified.

## **4. Discussion**

Among the tropical seas in the Indian Ocean, the Sea around the Andaman Nicabar islands is one of the important biodiversity hotspots (Nair and Gireesh, 2010), reported as oligotrophic (Qazim and Anzari, 1981), pristine and self sustaining system (Pai, 2007). The coastal waters of these islands are extremely important due to its ecological significance with the richest coral reefs and mangrove resources. The present study observed marked seasonal



difference in the environmental variables which is similar to the earlier observations made (Rangarajan and Marichamy, 1972; Eashwar et al. 2001) from different coastal regions of the Andaman Islands. However, only marginal seasonal variation was observed in Chl. *a* at both the regions which is in contrast with the observation of Nair and Gopinathan (1983). Similarly, the seasonal variation of mesozooplankton standing stock also showed insignificant variation. The marked coastal/oceanic/ and seasonal variations in productivity pattern experiencing in different Indian coastal waters are mainly due to the influence of heavy river runoff/coastal upwelling/land drainage etc. Even though the rivers such as Irrawaddy and Salween discharge enormous quantity of fresh water in to the Andaman Sea in the northern region, such influence up to the coastal waters of these islands are comparatively unsound. Beside this, only small scale upwelling processes have been reported from this region might be the factors for the limited seasonal variation observed in this area. Even though marginal seasonal variation was observed in Chl. *a*, marked spatial variation was observed in its distribution from outer to the interior of the PBB; irrespective of the season, and no such difference was observed at MPA. Eashwar et al. (2001) also reported an increase of Chl. *a* at the innermost point of the PBB. The increase of Chl. *a* from outer to the interior of the bay indicates the land derived nature of nutrients. Also the minimum wave disturbances inside the bay along with shallow depth, occurrence of corals and mangroves which creates a more or less estuarine environment may also have increased the sustainability of nutrients in the bay, resulting in increased production in this area.

The present study observed marked difference in Chl. *a*, mesozooplankton standing stock and community structure between PBB and MPA. Significantly higher Chl. *a* as well as zooplankton production were observed at PBB compared to MPA. Limited number of earlier reports from the coastal regions of these oceanic islands forms a major constraint for a comparative study. Gopinathan and Rajagopalan (1983) and Pillai (1983) suggested that increase in biological production in the coastal waters of these islands may be attributed primarily to the rich mangrove and coral reef resources, as these ecosystems play a vital role in primary production and in turn provides food and shelter for zooplankters and thereby accelerating the secondary production. This may be true in the present case also. However the marked difference obtained in production pattern between the two study areas suggest that the higher production in the PBB might be due to the anthropogenic inputs which is not experienced in MPA. The earlier studies from this region also are in support of this observation. For instance

Eashwar et al. (2001) and Dharani et al. (2004) reported recurrent phytoplankton bloom (Chlorophyll *a* up to 17.6 mg.m<sup>-3</sup>) from the PBB and the later suggested that the localized enrichment of nutrients by terrigenous and allochthonous inputs to the coastal waters of PBB may be one of the important causative factor. Also abundance of indicator bacteria has been reported from the PBB by Nallathambi et al. (2002). The increased frequency in appearance of blooms throughout the world in the recent past has led to believe that a change in the marine planktonic ecosystems on a global scale is caused by human alterations to the coastal zone. Port Blair is the only real urban area among these islands with 86.25% of the enumerated urban population (Patnaik and Prasad, 2005) and it has shown an enormous increase by most of the growth standards, over 12 times in a span of 50 years (Andaman and Nicobar Administration, 1999 ; Census of India, 2003). Therefore it can be reasonably assume that in addition to the enrichment by mangroves and corals, the nutrient inputs due to the present anthropogenic interferences may be a major factor for increased biological production at PBB.

Among the mesozooplankton community at both regions, the dominance of copepoda observed was similar to that of the earlier reports (Marichamy, 1983; Madhupratap et al. 1981). Among the non copepod taxa, the carnivorous groups such as siphonophores (Thibault-Botha and Gibbons, 2005; Gibbons et al 1992) and chaetognaths (Reeve, 1980; Ekblad, 2008) were abundant at PBB, while filter feeders (appendicularians and decapods larvae) were dominant at MPA during all the seasons. The observed disparity in the mesozooplankton community structure between the two regions may primarily be related to the increased food availability at PBB than at MPA. The abundance of filter feeders like appendicularians is of prime importance, as they are dominant picoplankton feeders and their grazing impact is very high (Angel et al. 2003). The relative decrease of decapod larvae and fish larvae at PBB compared to MPA may be due to high predation pressure (Devi et al. 1996) or by the prevalence of hostile ecological conditions for the larval existence/development in the bay. The abundance of decapod larvae, cyprid larvae, gastropod larvae and fish eggs noticed during SWM at the both regions can be related to the coincidence of their breeding season (Paulinose, 1979).

The taxonomy of copepod is relatively unknown from this region despite their dominance in the zooplankton community, both in terms of diversity and abundance. Copepod species diversity was high during NEM, and during all the seasons it consisted of a mixture of neritic and

oceanic species, indicating the prevalence of oceanic condition even in the coastal area. Most of them are Indo-Pacific in origin and a few are cosmopolitan in nature. Among the calanoid copepods, dominance of small copepods belonging to the family Paracalanidae was observed in both regions and their dominance in the Indian waters has been reported (Smith et al. 2005; Stephen et al. 1992). In addition, many of the recent studies have revealed the significance of small copepods (Calbet et al. 2000; Satapoomin et al. 2004) as they are efficient in utilizing even the picoplankton component in the water column. Eashwar et al. (2001) revealed the presence of innumerable green flagellates on *Noctiluca* and high levels of Chl. *c* from the PBB during the time of *Noctiluca* bloom and the study supposes that the high Chl. *c* may be derived from the bacterial chlorophyll. It indicates the chances of abundance of picoplankton component in the water column. Therefore, the present study assumes that, the energy transfer mediated by bacterioplankton is significant in the trophic structure of the coastal waters of Andaman Islands. The noticeable increase of eucalanids observed during SWM and pontellids during IM could be related to the changing scenario in food availability and salinity pattern. Poecilostomatoid and cyclopoid composition was observed as higher during NEM. The dominance of poecilostomatoids and cyclopoids from the Indian Ocean during NEM has been reported (Smith et al. 1998; Stephen, 1988). The swarming of *Undinula vulgaris* observed during NEM at MPA and their dominance was reported from the inshore waters of Indian Ocean (Madhupratap and Haridas 1986). The abundance of *Macrosetella* sp. noticed at MPA may be more related to their affinity to the coral reef environment.

The composition of chaetognath species showed dominance of Indo-Pacific fauna. *Sagitta bipunctata* and *S. enflata* were the only cosmopolitan species found in the area. The dominance of *S. neglecta* was often outnumbered by *S. enflata* and this is a peculiar feature for the eastern Indian Ocean (Nair, 1977). Species diversity of chaetognath observed was high as compared to the west coast of India (Nair and Ramaiah, 1996). The chaetognath species such as *S. meenakshiae* and *K. balagopali* observed from these regions have been reported as endemic (Nair et al. 2008). Significant contribution of decapod larvae was observed during the present observation which is similar to the report of Paulinose and George (1976). The larval diversity and the relative contribution of different families were observed to be high at MPA and were dominant during the monsoon seasons than IM. It indicates that MPA provides an environment more conducive for the larval development compared to PBB. Even though the food availability

is high at PBB, the high predation pressure may be a major reason for reduction in larval survival.

## **Conclusion**

Andaman and Nicobar group of islands are reported as the pristine and self sustaining system. However, the present study reveals the difference in production pattern and mesozooplankton community structure between the two coastal regions of south Andaman Island. It appears that PBB may be under the influence of anthropogenic activities thereby supporting a dynamic food web, whereas the MPA is comparatively more diverse and conducive for larval survival and sustaining an ideal community. In support of this, recurrent phytoplankton blooms and presence of indicator bacteria have also been reported from the bay. The richness of marine biota of these islands is mainly linked with the renowned coral reefs and the extensive mangroves of these islands. Since these ecosystems are very sensitive, it is suggested that more attention should be paid to preserve and protect the marine prosperity of these islands.

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**Table 1.** Two Way nested ANOVA for unequal samples

<b>Source of Variation</b>	<b>Among areas</b> $F_s$ (1,25)/ $F's$ (1,4)	<b>Among seasons</b> $F_s$ (4,25)	<b>Source of Variation</b>	<b>Among seasons</b> $F_s$ / $F's$	<b>#Among species/groups</b> $F_s$
Temp.	0.084/0.001	53.68	PBB Chaetognath species	14.67 (2,130)/ 4.47(2,23)	3.28 (23,130)
Sal.	1.47/0.1037	14.11	PBB Decapod family	0.30 (2,125)/0.12(2,22)	2.55(22,125)
DO	0.01/0.0096	13.82	PBB Copepod Family	1.35 (2,255)/0.65(2,48)	2.07(48,255)
Chl. a	3.23/7.82	0.42	MPA Chaetognath species	0.28(2,72)/0.17(2,19)	1.67(19,72)
Biomass	69.98/262.33	0.27	MPA Decapod family	7.89(2,104)/2.52(2,42)	3.13(42,104)
Density	35.21/71.90	0.49	MPA Copepod Family	0.43(2,178)/0.13(2,51)	3.46(50,178)
<b>Remarks</b>	<b>Significance</b>	<b>P value</b>	<b>Remarks</b>	<b>Significance</b>	<b>P value</b>
Temp.	NS	P<0.05	PBB Chaetognath species	P<0.05/ P<0.05	P<0.05
Sal.	NS	P<0.05	PBB Decapod family	NS/NS	P<0.05
DO	NS	P<0.05	PBB Copepod Family	NS/NS	P<0.05
Chl. a	NS	NS	MPA Chaetognath species	NS/NS	P<0.06
Biomass	P<0.001	NS	MPA Decapod family	P<0.01/NS	P<0.05
Density	P<0.01	NS	MPA Copepod Family	NS/NS	P<0.05

**Table 2.** Percentage contribution of different groups

	PBB			MPA		
	NEM	IM	SWM	NEM	IM	SWM
Foraminifera	0	0	1.17	0	0	0
Hydrozoa	0.03	0.15	0.07	0	0.01	0
Siphonophora	9.77	9.72	5.96	1.88	0.25	0.04
Ctenophora	0.01	0.03	0.5	0.01	0	0
Polychaeta	0.05	0.12	0.28	0.18	0	0
Cyprid larvae	0	0	2.1	0	0	0.83
Pteropoda	0.04	0	1.15	0.07	0.5	0.04
Gastropoda	0	0	0.11	0	0	0.02
Cladocera	0	0	0	0.23	0	0
Ostracoda	0.01	0.01	0.21	0	0	0.17
Copepoda	85.95	81.73	81.03	83.18	92.65	81.9
Amphipoda	0	0.01	0.01	0.04	0	0
Euphausiids	0.07	0.01	0.01	0.02	0	0.5
Decapod larvae	0.07	0.12	0.33	3.51	1.87	5.4
Lucifer	0.01	0.26	0.51	1.07	0.26	1.68
Stomatopoda	0.01	0	0	0.12	0.01	0
Chaetognatha	1.96	3.69	2.63	3	2.13	2.17
Appendicularians	0.5	3.16	0.26	6.1	2.09	5.69
Salpa	0	0.01	0.03	0.07	0	0
Doliolida	0	0.07	0.07	0.06	0	0
Fish Eggs	1.49	0.9	3.53	0.42	0.21	1.49
Fish larvae	0.03	0.01	0.04	0.04	0.02	0.07

Table 3. Percentage contribution of copepod, chaetognath and decapod families/ species during different seasons

(a) Copepoda	PBB			MPA		
	NEM	IM	SWM	NEM	IM	SWM
Calanidae	6.90	3.66	2.22	23.68	2.04	4.00
Eucalanidae	0.28	0.13	37.52	1.30	0.44	25.00
Paracalanidae	70.33	63.65	53.10	27.00	65.00	40.00
Clausocalanidae	10.68	2.71	0.00	5.00	23.00	15.00
Scolecithricidae	0.00	0.00	0.19	0.03	0.00	0.30
Centropagidae	1.81	1.36	0.19	0.85	0.54	0.85
Pseudodiaptomidae	0.02	0.06	0.00	0.14	0.00	0.20
Temoridae	0.04	0.64	0.16	0.35	0.03	0.42
Lucicutiidae	0.00	0.04	0.02	0.00	0.01	0.04
Candaciidae	0.07	0.00	0.10	0.25	0.17	0.42
Pontellidae	0.05	2.32	0.02	1.38	0.56	0.04
Euchaetidae	0.00	0.00	0.00	0.00	0.01	0.00
Acartiidae	0.65	15.48	0.13	6.37	4.26	1.20
Tortanidae	0.00	0.00	0.05	0.00	0.02	0.00
Oithonidae	0.07	0.54	0.06	0.99	0.06	2.40
Sapphirinidae	0.04	0.00	0.02	0.26	0.45	0.04
Oncaeidae	7.28	1.79	1.05	12.67	0.22	3.00
Corycaeidae	1.76	7.41	5.11	15.33	2.93	7.00
Miraciidae	0.03	0.03	0.03	4.27	0.01	0.10
Euterpinidae	0.00	0.09	0.02	0.05	0.05	0.01
Longipediidae	0.00	0.11	0.00	0.00	0.00	0.00
Clytemnestridae	0.00	0.00	0.00	0.05	0.00	0.00
<b>(b) Chaetognatha</b>						
<i>Krohnia pacifica</i>	0.23	1.68	4.01	0.00	6.15	4.85
<i>K. balagopali</i>	0.33	0.00	2.43	0.00	1.09	0.00
<i>Pterosagitta draco</i>	1.92	0.00	6.55	2.39	0.00	0.21
<i>Sagitta bedoti</i>	0.78	0.00	0.47	1.75	0.00	1.63
<i>S. bipunctata</i>	2.35	0.00	0.00	1.29	0.00	0.00
<i>S. enflata</i>	46.77	34.40	68.81	49.66	33.46	61.50
<i>S. ferox</i>	0.03	14.46	0.00	0.00	1.69	2.70
<i>S. neglecta</i>	12.55	16.10	40.35	13.20	46.32	24.62
<i>S. pacifica</i>	0.32	0.00	0.00	0.00	0.00	0.00
<i>S. regularis</i>	1.34	0.00	0.17	2.23	0.00	1.00
<i>S. pulchra</i>	0.00	0.00	0.00	29.49	0.00	0.00
<i>S. robusta</i>	0.00	2.03	0.17	0.00	5.09	3.50
<i>S. meenakshiae</i>	3.52	31.32	6.90	0.00	6.20	0.00
<b>(c) Decapod larvae</b>						

Sergestidae	1.04	0.00	1.28	0.00	0.00	0.00
Penaeidae	0.00	1.83	13.54	0.99	2.78	0.37
Procarididae	0.00	0.00	0.00	0.00	0.00	0.12
Pasiphaeidae	0.00	0.00	3.31	0.00	0.90	1.79
Alpheidae	49.62	34.20	18.89	23.10	20.47	25.15
Pandalidae	0.00	10.51	2.93	28.88	1.34	1.49
Hipolitidae	0.00	0.00	0.00	0.00	0.00	0.35
Processidae	0.00	0.00	0.00	0.00	0.00	0.36
Palaemonidae	3.11	41.48	28.32	0.00	37.40	11.95
Pontonidae	0.00	0.00	0.00	0.00	0.00	0.04
Palaemonidae	0.00	0.00	0.00	0.00	0.00	19.05
Crangonidae	0.00	0.00	0.00	2.26	0.45	0.71
Axiidae	14.72	0.00	4.21	1.96	0.99	12.29
Callinassidae	0.00	0.00	0.00	1.26	0.00	0.20
Upogebiidae	2.07	0.00	4.44	0.60	6.66	4.79
Galathidae	1.44	0.00	0.00	0.49	3.33	1.57
Porcellanidae	4.40	0.00	0.00	0.57	2.34	1.56
Paguridae	2.89	0.00	13.47	7.20	6.12	6.83
Diogenidae	0.00	0.00	0.00	0.00	0.45	1.42
Albunidae	0.00	3.98	0.00	0.25	0.00	0.55
Palinuridae	0.00	0.00	0.00	0.00	0.90	0.00
Brachyuran larvae	20.73	7.96	9.64	32.45	15.88	9.40

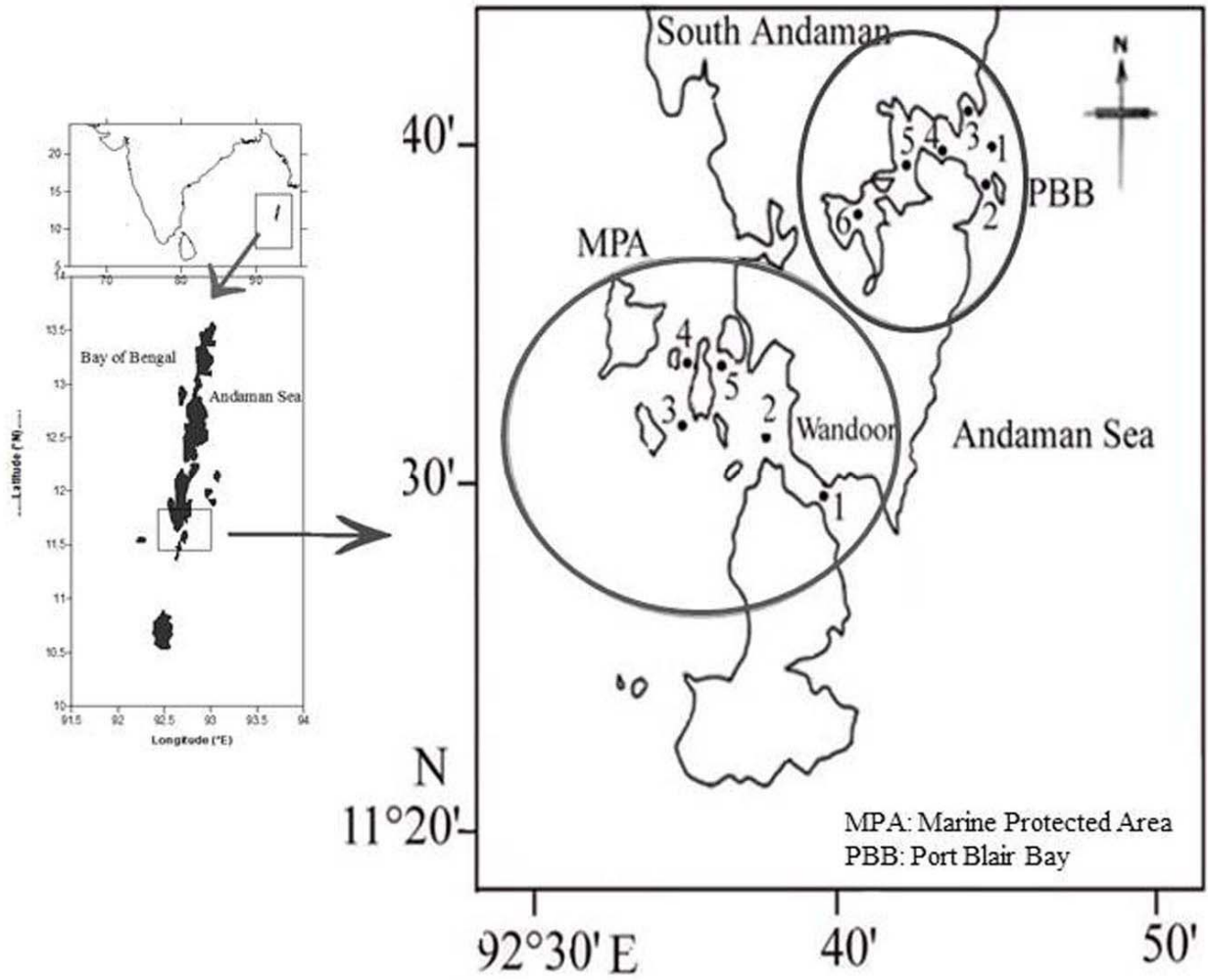
**Table 4.** Community structure indices

Based on	Diversity index			Dominance index		
	MPA IM	MPA NEM	MPA SWM	MPA IM	MPA NEM	MPA SWM
Chaetognath (species)	1.12	0.54	1.45	0.98	0.23	0.78
Decapods larvae	1.30	2.39	2.53	0.62	1.27	0.88
Copepod (families)	1.51	2.48	2.43	0.35	0.37	0.76
Based on	PBB IM	PBB NEM	PBB SWM	PBB IM	PBB NEM	PBB SWM
Chaetognath ( species)	1.42	1.039	1.40	0.98	0.52	0.64
Decapods larvae	0.87	1.26	2.09	1.09	1.03	1.57
Copepod (families)	1.60	1.49	1.41	0.53	0.41	0.28

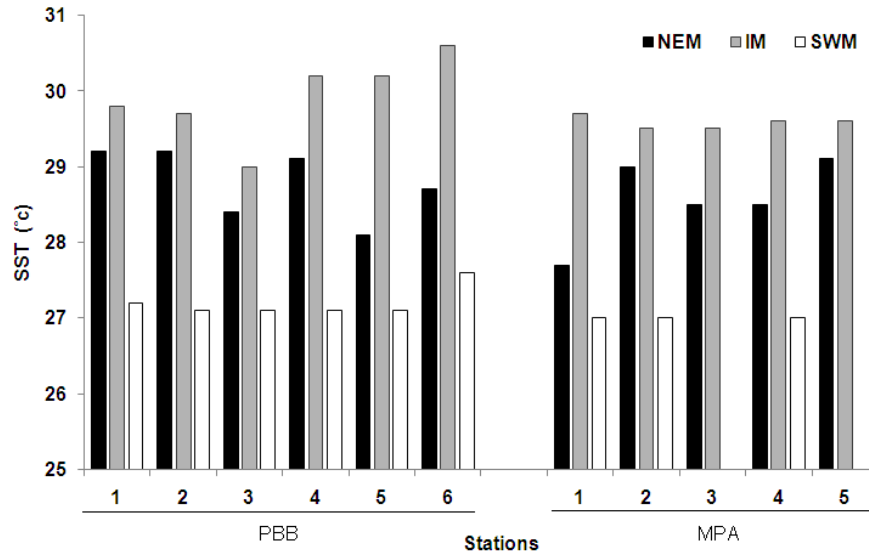
**Table 5.** The discriminant analysis Cross validated results

Season/area	PBB NEM	PBB IM	PBB SWM	MPA NEM	MPA IM	MPA SWM
PBB NEM	16.67	16.67	0	33.33	33.33	0
PBB IM	50	0	0	0	33.33	16.67
PBB SWM	50	0	16.67	0	0	33.33
MPA NEM	40	0	20	0	0	40
MPA IM	20	0	0	20	0	60
MPA SWM	0	33.33	0	0	0	66.67

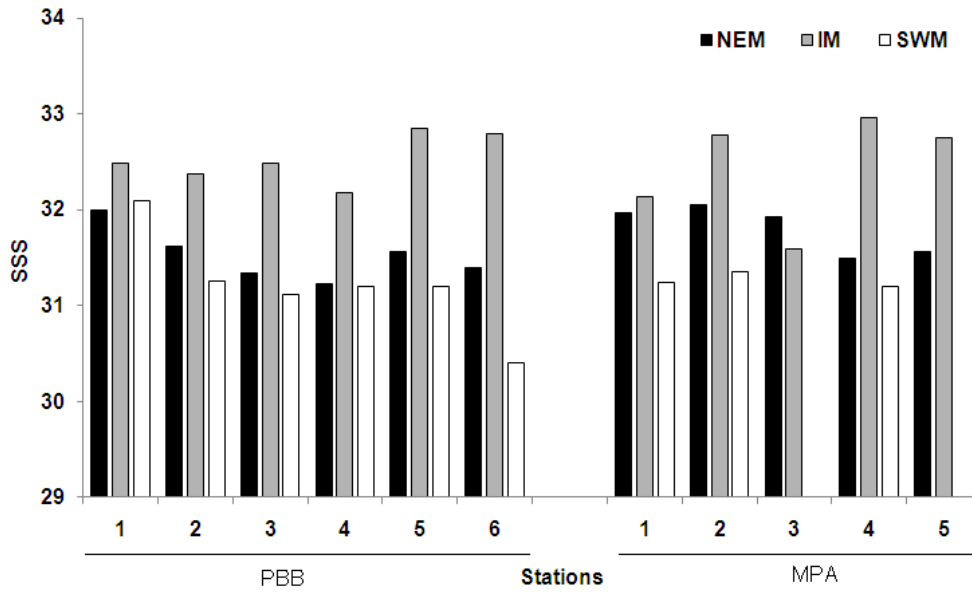
**Fig. 1 Station locations**



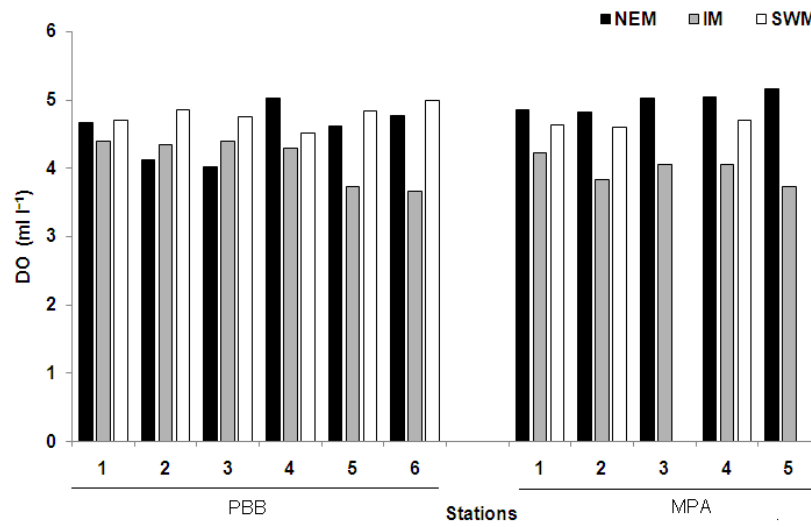
**Fig. 2 a. Temperature distribution**



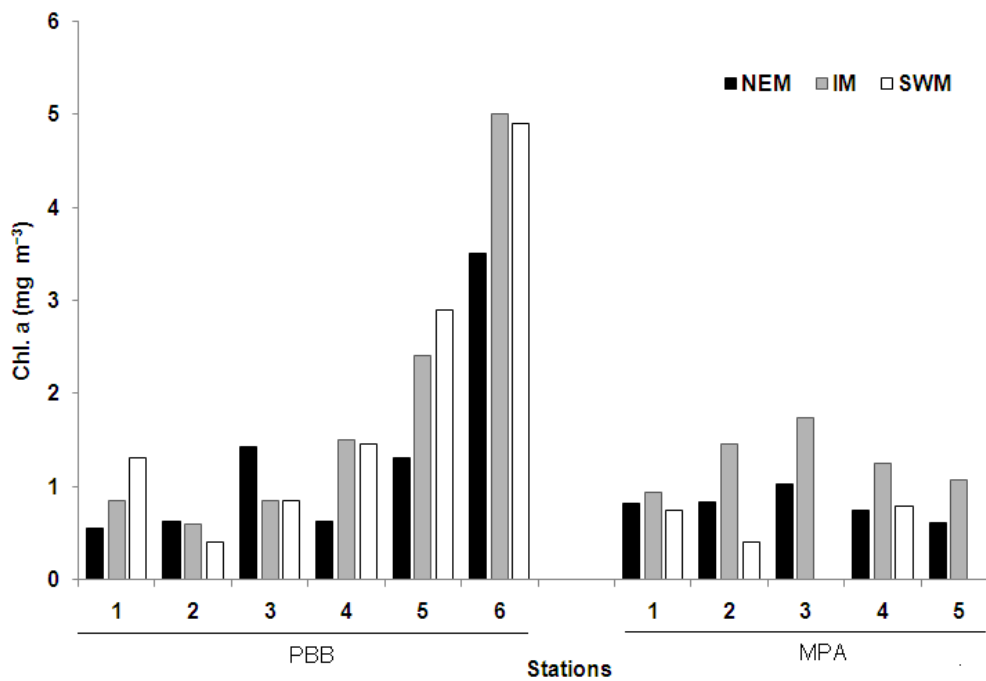
**Fig. 2 b. Salinity distribution**



**Fig. 2 c. Dissolved Oxygen distribution**

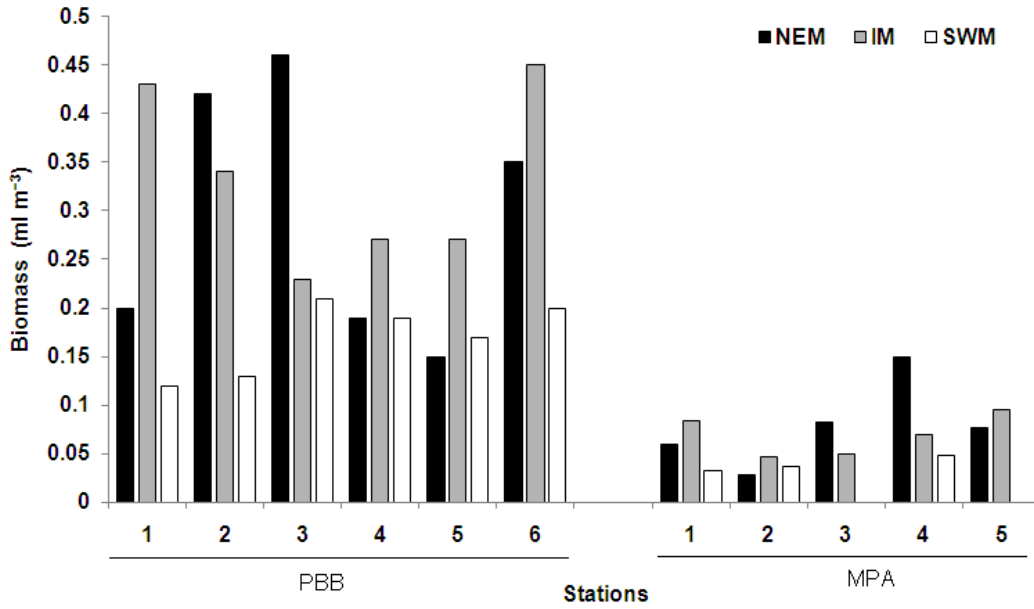


**Fig. 3 Chl. *a* distribution**

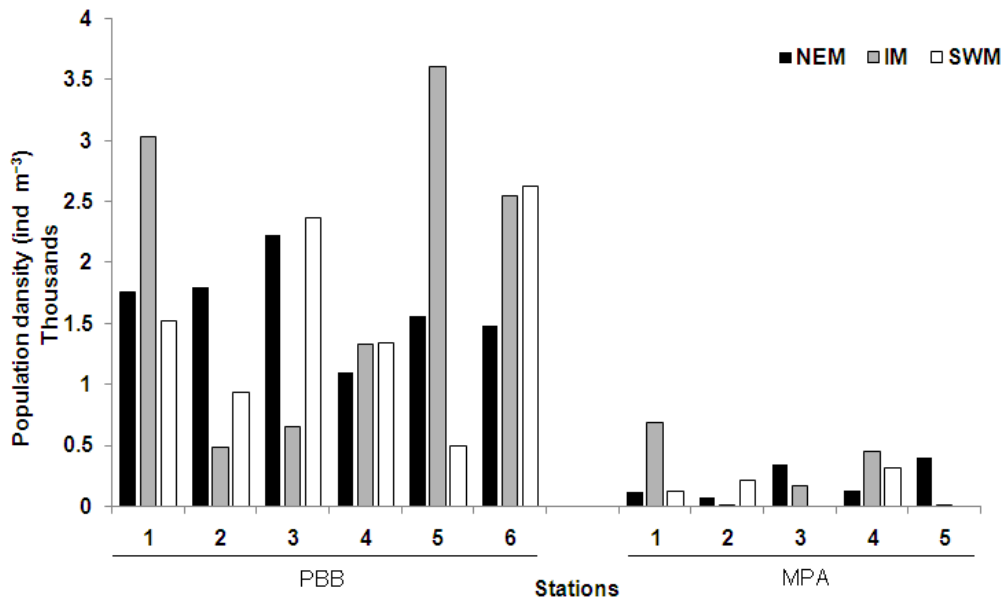




**Fig. 4 Mesozooplankton biomass distribution**



**Fig. 5. Mesozooplankton density distribution**



**Fig. 6**

DISCRIMINANT PLOT FOR MARINE PROTECTED AREA AND PORT BLAIR BAY BASED ON ALL SEASONS

